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Regional Variability: Causes for contemporary Regional Sea Level Changes

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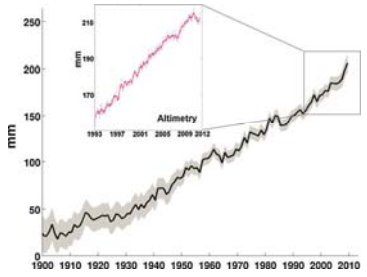
Prolog

- Sea level is one of the climate parameters with immediate societal relevance. It is effected by almost all climate components and its changes are an integral measure of climate change.
- Regional sea level changes have many more contributions that global sea level, both dynamic and static in nature.
- In addition, local sea level has also strong contributions not related to present climate change, including anthropogenic changes.
- Analyses of sea level have strong ties to observations as well as modeling and theory.

Recall: Global mean sea level is rising…



Church and White, 2011

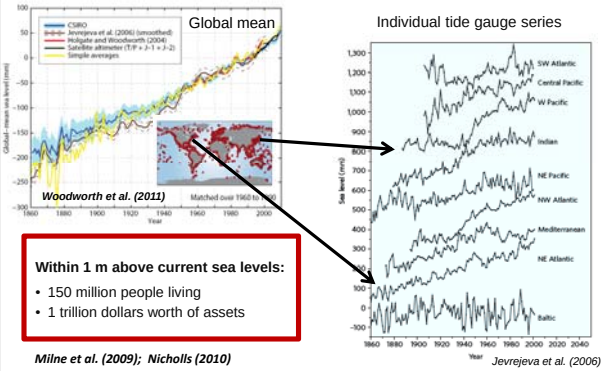
20th-century:
~ 1.7 mm/yr

Altimetry (since 1993):
~ 3.2 mm/yr

Causes (last 20 yrs):

- ocean warming ~ 30-40 %
- glaciers melting ~ 30%
- ice sheets: recent increase to >25%

But it is the regional/local sea level variations that matter to society

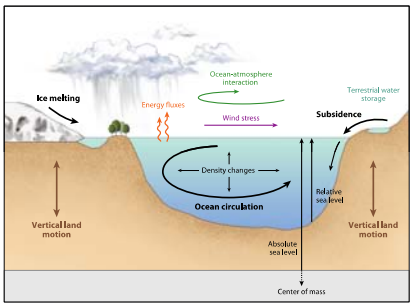


Within 1 m above current sea levels:

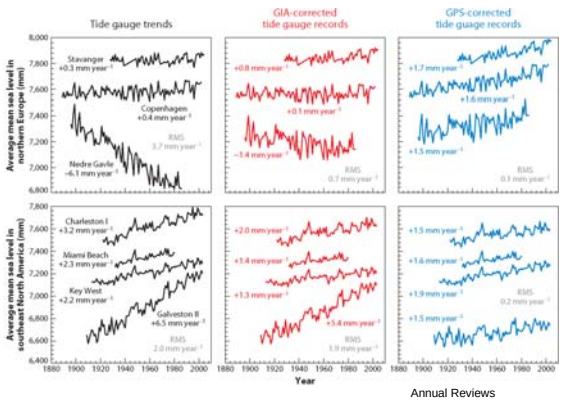
- 150 million people living
- 1 trillion dollars worth of assets

Milne et al. (2009); Nicholls (2010)

Processes Causing Regional Sea Level Change



All these processes need to be considered in combination for estimates of future global or regional sea level change.

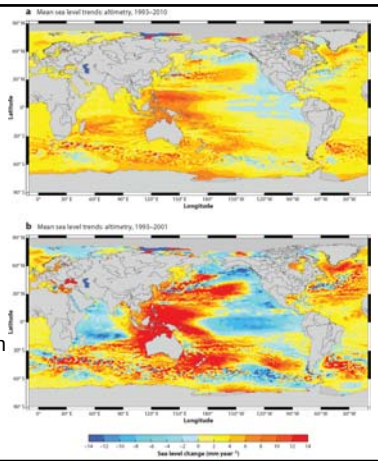


Annual Reviews

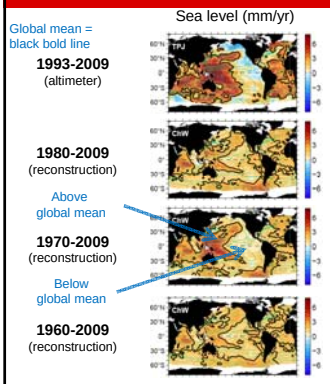
Strong Pattern of Altimetric Sea Level Trend (mm/yr)

1993-2010

1993 – 2001; without global mean



Regional sea level trends vary with time …



Sea level trends for shorter periods (e.g., 1993-2009) can **differ** from longer-term periods (e.g., 1960-2009).

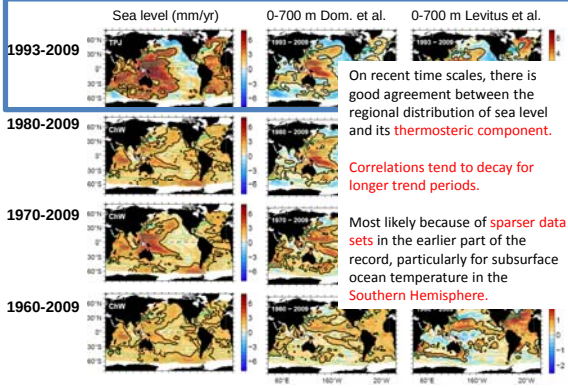
In part, due to natural climate variability ranging from interannual, decadal, multi-decadal and longer timescales. (e.g., **modes of variability**: ENSO, PDO, IOD, NAO, SAM, AMO, etc)

Natural climate variability masks anthropogenic sea level changes and can also be modified by anthropogenic forcing.

TPJ = Topex-Poseidon/Jason
ChW = Church and White (2011)

Domingues et al. (in prep.)

(Thermo)steric nature of regional sea level change



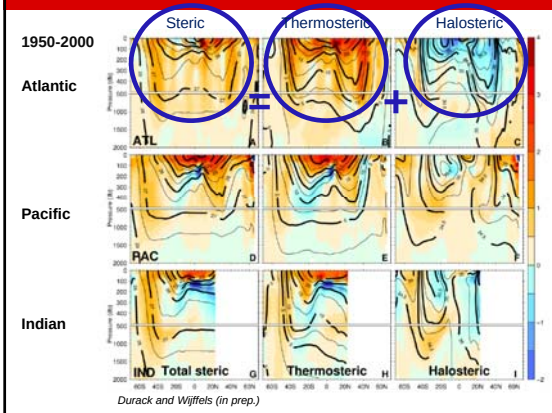
On recent time scales, there is good agreement between the regional distribution of sea level and its thermosteric component.

Correlations tend to decay for longer trend periods.

Most likely because of sparser data sets in the earlier part of the record, particularly for subsurface ocean temperature in the Southern Hemisphere.

Domingues et al. (in prep.)

Regional role of salinity (halosteric contribution)

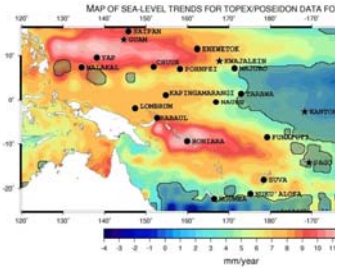


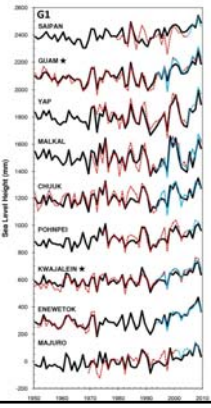
Durack and Wijffels (in prep.)

See also: Kohl and Stammer (2008); Ponte (2012)

Sea level reconstructions at tropical Pacific Islands since 1950:

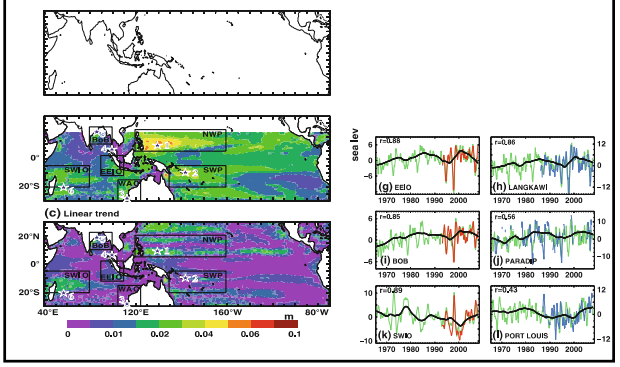
Variability imposed by climate modes.



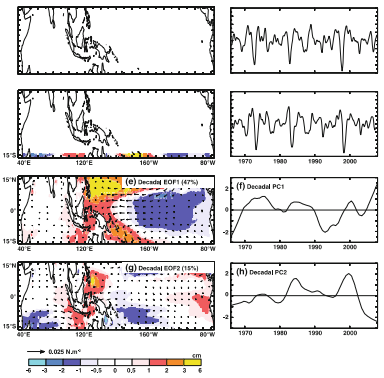


(Becker et al., 2012)

Decadal and long-term sea level variability in the tropical Indo-Pacific Ocean (Nidheesh et al: 2012):



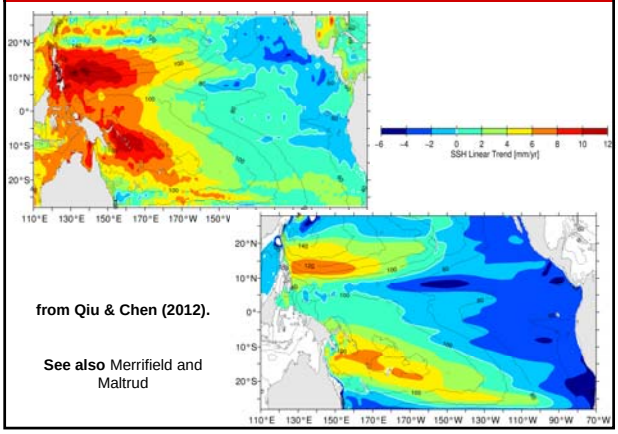
Decadal and long-term sea level variability in the tropical Indo-Pacific Ocean



Inter-basin scale wind variations as driver for interannual variabilty.

Basin-scale wind variations on decadal time scale independent between basins.

Observed vs Modeled Sea Level Rise: 1993-2009

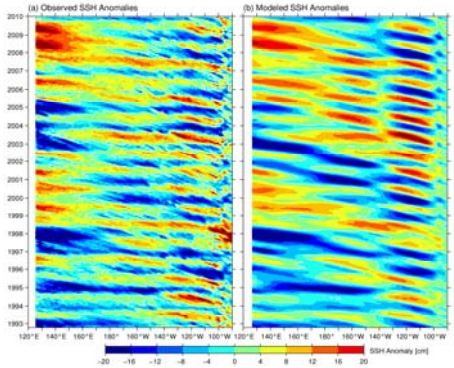


from Qiu & Chen (2012).

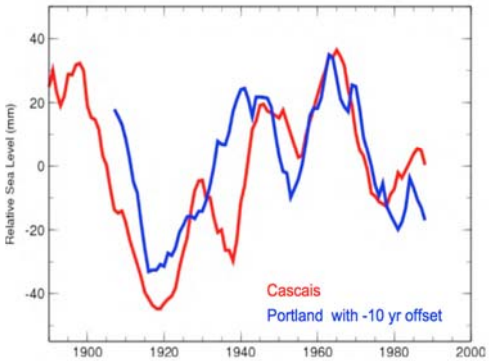
See also Merrifield and Maltrud

Observed and simulated sea level anomalies along 12°-14°N

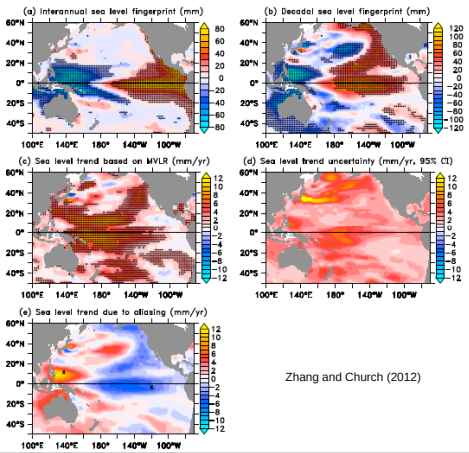
Qiu & Chen (2010).



Sea level measurements at Cascais, Portugal (*red*), and Portland, Maine (*blue*)

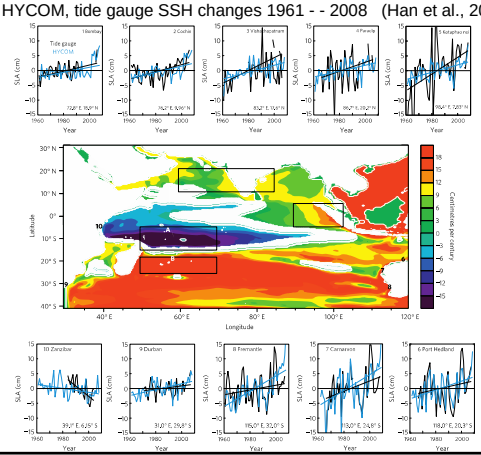


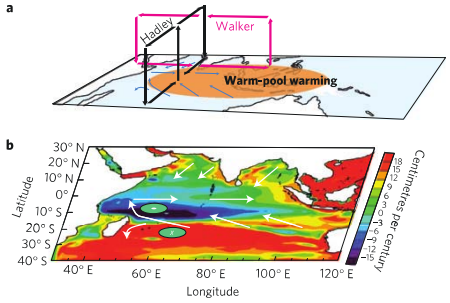
Miller and Doughlas



Zhang and Church (2012)

HYCOM, tide gauge SSH changes 1961 - - 2008 (Han et al., 2010)





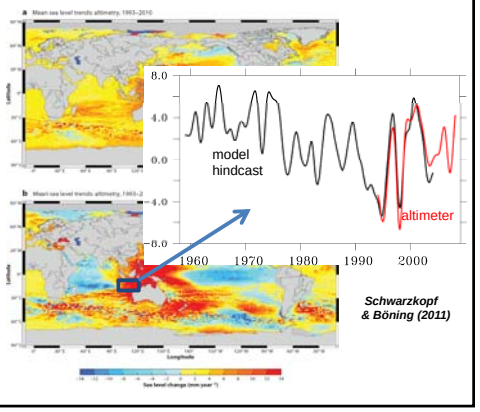
Schwarzkopf and Boening: wind changes in Pacific also important.

Figure 4 | A schematic diagram showing the mechanisms for the Indo-Pacific warm-pool warming to cause the Indian Ocean sea-level change. Warming enhances the Indian Ocean regional Hadley and Walker cells (**a**); the two enhanced cells combine to form a specific pattern of surface wind change (surface arrows in **a** and **b**) together with the Ekman pumping velocity (positive—circle with dot; negative—circle with x), which drive the distinct sea-level pattern (colour contours in **b**).

Example of strong temporal SSH variability

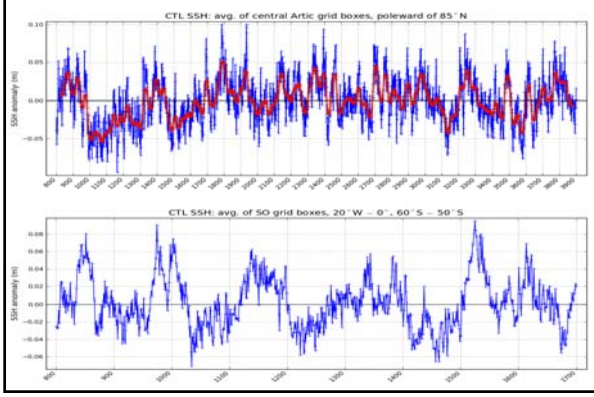
1993 - 2010

1993 - 2001

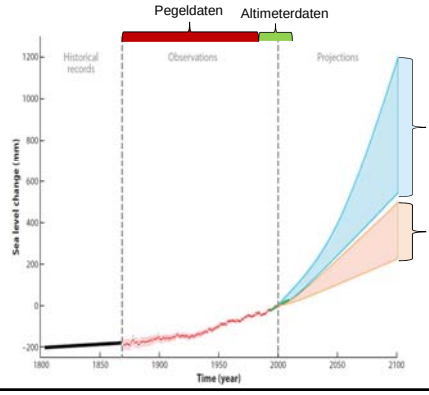


Schwarzkopf & Böning (2011)

Millennium Sea surface height anomaly time series (J. Jungclaus, M. Carson)



Evolution Global Mean Sea Level 20th and 21st Century



Semi-empirical Methods. Rahmstorf (2007), Jevrejeva et al.(2010)

CMIP3 Projections using process based models

IPCC (2007) AR4

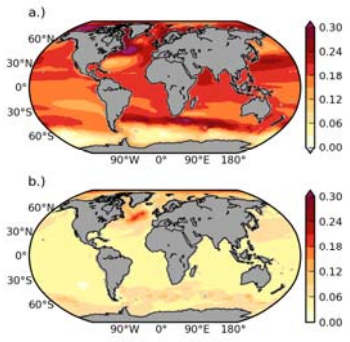
What about CMPI5?

CMIP5 Projections of Regional Sea Level (in m)

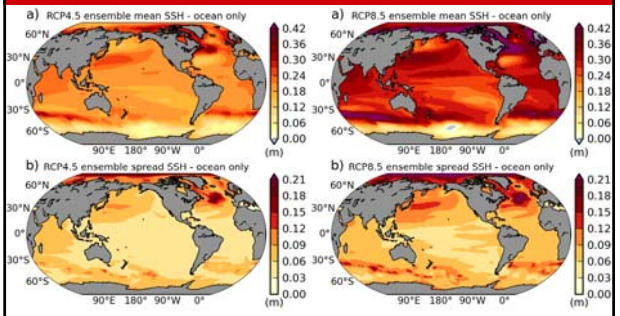
CMIP5 Ensemble mean (RCP4.5; 21 models) 2081-2100 minus 1986-2005 shows clear signs of changing ocean dynamics.

Ensemble Spread

From Slangen et al., 2013

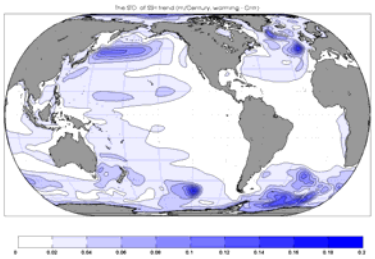


CMIP5 Projections of Regional Sea Level (in m)



Strong internal variability

→ Regional SL changes dependent on initial conditions



M. Latif (pers. comm.)

Ensemble standard deviation (m/century) from 22 integrations
(1%-increase: CO2 doubling after 70 years, then CO2 constant for another 30 Years)

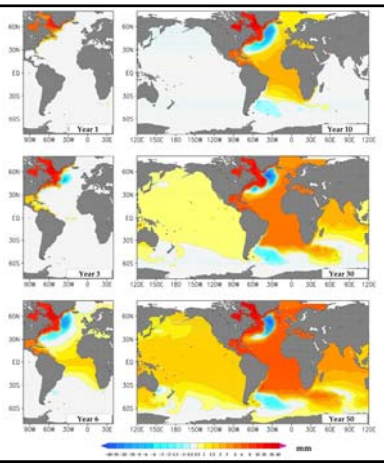
What else is missing in Climate Models?

- Ice sheet dynamics (melt water)
- Dynamical ocean adjustment to melt water
- Atmospheric loading
- Land hydrology
- Uncertainties (not missing but unknown!)

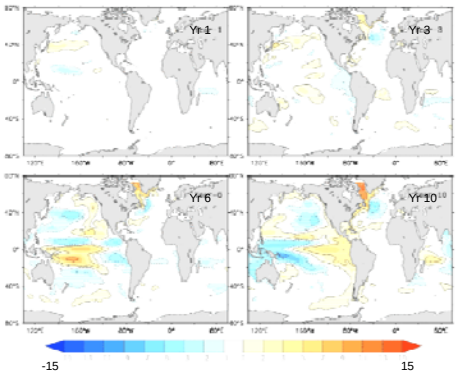
Ocean-only SSH Response to Greenland meltwater injection:

Has a fast barotropic component (e.g. Lorbacher et al., 2012)

But has certainly also a baroclinic long-term component (Stammer, 2008)



Coupled SSH Response to melt water injection (cm)



Summary

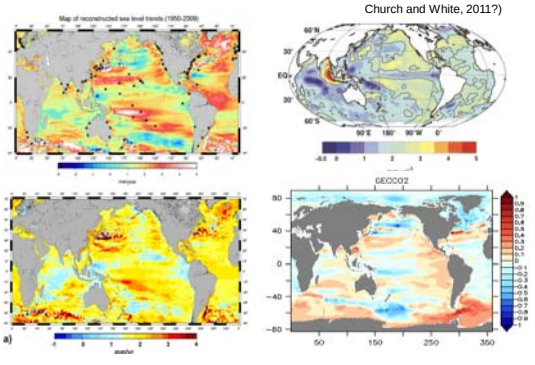
- Regional SSH trends are substantially different from global trends; presently they largely represent climate variability superimposed to global trend; however, over the next 100 yr will see more of a trend.
- Contemporary changes are mostly due to changes in heat content; but salinity changes contribute as well, especially over the last 50 years.
- There is substantial internal variability on the decadal to centennial time scale. Wind stress changes appear to be an important driving force.
- On longer time scales heat uptake and static effects from solid earth become dominant!
- There remain substantial uncertainties in existing reconstructions and projections.

Reconstruction of past sea level 1951-2001

Church and White, 2011?)

Becker et al. (2012)

Meyssignac & Cazenave (2012)



Open Issues (incomplete).

Estimates of relative contribution of climate modes to sea level variability.

Intercomparison of climate modes in climate models and observations (amplitudes, periods, phases, internal structures).

Change of climate modes as function of CO2 forcing.

Separation of climate modes and long-term trends (in observations and in models).

Investigation of contributions of wind forcing changes relative to other forcing components on regional sea level variability and secular changes.

Impact of changes in the wave field on sea level need to be investigated.

Improve understanding of dynamical response of sea level to climate forcing, including high latitude freshwater forcing.

Thank you!